*Central Chile has had a higher frequency of drought for two centuries, and one sensitive indicator of this climate change is the endemic conifer,* Fitzroya cupressoides. *Its remarkable history is a story of contradiction.* Fitzroya cupressoides *is a millennial survivor of large-scale disturbances: glaciers, volcanic eruptions, and earthquakes. Its gradual decline is recent, beginning before the arrival of early humans, and then accelerating with agricultural clearing and logging. Now on IUCN's Red List as an endangered species,* Fitzroya cupressoides *and its history bring fresh understanding as to how Southern Hemisphere forests have responded to past climate change in ways distinctly different from those of the Northern Hemisphere.*

# A HISTORY OF PERSISTENCE

## *AND DECLINE—FOR A SOUTHERN HEMISPHERE CONIFER,* FITZROYA CUPRESSOIDES

*Fitzroya cupressoides* belongs to a monotypic genus within the Cupressaceae family. Its scientific name was bestowed by Charles Darwin in honor of Robert Fitzroy, captain of the HMS *Beagle*. In *The Voyage of the Beagle*, Darwin mentioned this tree by its common name, *alerce*, in his account of an attempt to climb Mount San Pedro on San Pedro Chiloe Island on December 6, 1834. "In vain we tried to gain the summit," Darwin recorded. "The forest was so impenetrable, that no one who has not beheld it can imagine so entangled a mass of dying and dead trunks. I am sure that often, for more than ten minutes together, our feet never touched the ground, and we were frequently ten or fifteen feet above it, so that the seamen as a joke called out the soundings…. On the higher parts, brushwood takes the place of larger trees, with here and there a red cedar or an alerce pine." Darwin also mentioned seeing the indigenous Mapuché people carrying *alerce* planks, but he did not use their name for the tree, *lahuan* (Darwin [1839] 1972).

Not only is this the tallest tree found in South America but it also has the longest lifespan—with some individuals stretching back three millennia. Part of the South American temperate forest, *Fitzroya* has a narrow range that can be described as a transect running across south-central Chile into Argentina. Inclusive of the Valdivian rain forest, the transect crosses the Cordillera de la Costa, which runs parallel to the Pacific Ocean, into the Central Valley depression, and then up into the Andes

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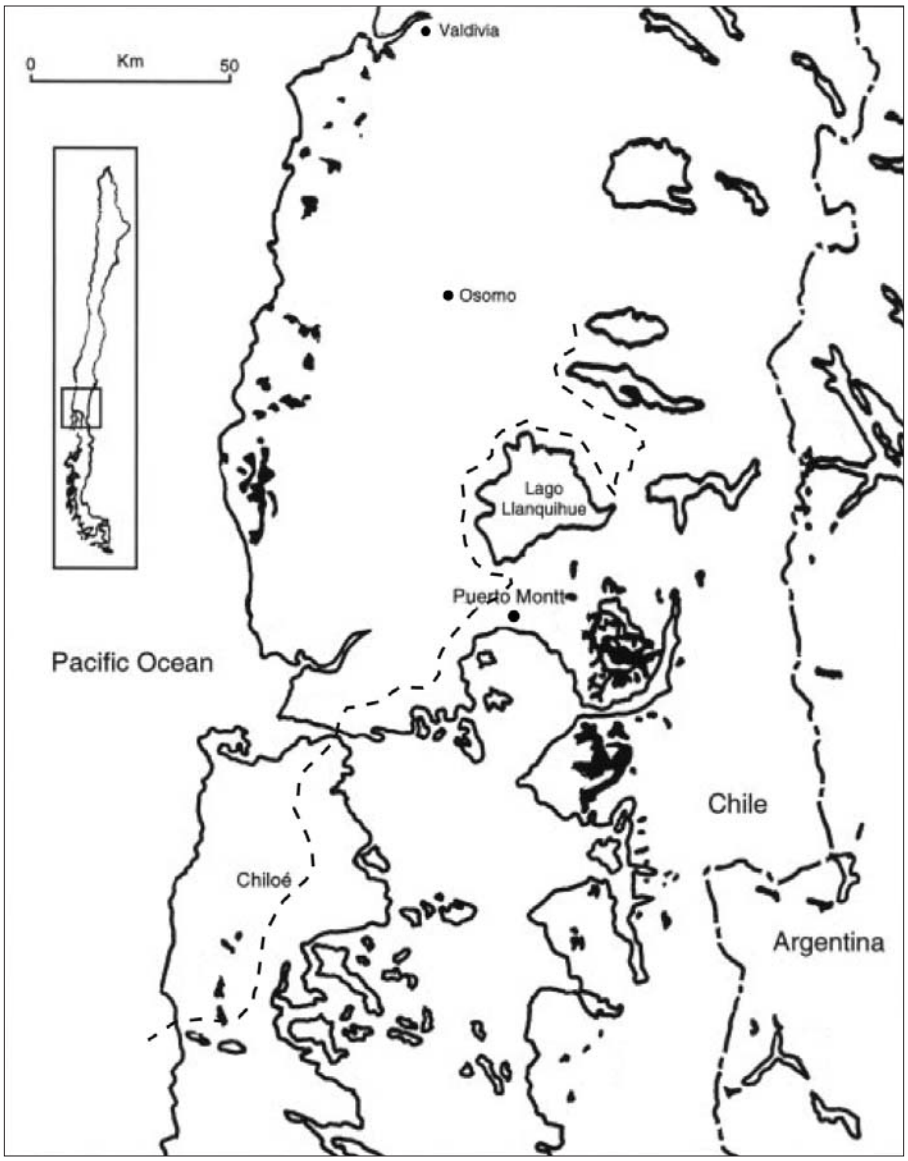
Fitzroya cupressoides *(Molina) I.M. Johnst. is the conical-shaped tree on the right. The broadleaf tree on the left is a* Nothofagus.

Mountains range, crossing into Argentina (Kitzberger et al. 2000). Its range overlaps with that of other forest tree species of the Southern Hemisphere: evergreen beeches (*Nothofagus* spp.) and a few conifers, including the monkey-puzzle tree (*Araucaria*) and Patagonian cypress (*Austrocedrus chilensis*). Another conifer, the Guaitecas cypress or *Pilgerodendron uviferum*, also grows in the same wet, boggy soils as *Fitzroya cupressoides*. This requirement for wet, boggy soils makes *Fitzroya* a sensitive indicator of

climate change (Roig et al. 2001).

The oldest *Fitzroya cupressoides* specimens reach 50 meters in height with a diameter of 4 to 5 meters (e.g., Heusser 1966). The occasional *Fitzroya* trees grow intermingled in a dense forest of trees, lianas, epiphytes, ferns, and herbaceous species. This is the case in the Valdivian rain forest where soils are boggy from rainfall delivered by east-blowing storms coming off the Pacific Ocean during winter months (Roig et al. 2001). Pure stands, or the *alercal*, have long since been logged out in other parts of the species' range.

After Darwin's early exploits, *Fitzroya cupressoides* acquired another common name, South American redwood. Its beautiful redwoodlike grain drew loggers to the Patagonian *alercal*. Chilean poet Pablo Neruda remembered these Patagonian forests well from his childhood in Temuco. In *Memoirs*, Neruda wrote, "The frontier regions sank their roots into poetry and these roots have never been able to wrench themselves out. My life is a long pilgrimage that is always turning on itself, always returning to the woods in the south." Later he added, "There the huge trees were sometimes felled by their seven hundred years of powerful life, uprooted by storms, blighted by the snow, or destroyed by fire" (Neruda 1974). To this list we should add logging, sparse regeneration, and gradual climate change. All have contributed to the present-day scarcity of *Fitzroya cupressoides*.




ALLNUTT ET AL. 1999

*Sketch map showing the current distribution of* Fitzroya cupressoides *(black, filled areas). The distribution map is based on that provided by Donoso (1993). The dashed line marks the supposed limit of the ice sheet during the glacial maximum (after Villagrán 1991).*

## FIRE AND THE GOLDEN AGE OF LOGGING

The species is sensitive to fire (Veblen et al. 1999), so its decline probably began with the increased fire incidence that accompanied the arrival of humans roughly 12,500 to 14,500 years ago. Aboriginal people sought hunting grounds and later practiced slash-and-burn agriculture (see review in Armesto et al. 2010). Incidence of fire increased even more after the Spanish conquest (A.D. 1550–1600) and the introduction of large-scale logging. The Spanish exported large volumes of timber to colonies in Peru and later to Europe. Mining discoveries led to hundreds of copper smelting furnaces, all wood-fired. The Spanish also introduced cattle and cleared agricultural land to provide food to miners, local and abroad. After independence, Chilean wheat exports fed miners during California's Gold Rush. By the mid-nineteenth century, Chile was well into its golden age of logging.

By then, railways transported logs to the ports, where Chile derived 15 percent of its national income from foreign trade (Armesto et al. 2010). Timber was sawn by portable steam-powered sawmills that were moved from camp to camp as loggers sought more stands to cut. Settlers burned 300,000 ha of Patagonian forests in south-central Chile between 1920 and 1950; this area has not returned to forest cover.

Forest policy was slow to change in Chile, and when it did, the national emphasis shifted to plantation species, which were more amendable to silviculture than *Fitzroya* and its associated species. Even so, both Chile and Argentina recognized the need for conserving dwindling reserves of *Fitzroya cupressoides*. In 1976, three years after Argentina enacted strict logging prohibitions, Chile followed suit. Today *Fitzroya* is a protected species within national preserves such as the Alerce Andino National Park in Chile and Los Alerces National Park in Argentina. Even so, two-thirds of the original forest did not regenerate, and only 15 percent of the original *Fitzroya* forests remain today (Armesto et al. 2010). *Fitzroya cupressoides* numbers among the world's endangered conifer species and the species is also protected by the Convention on International Trade in Endangered Species (CITIES).

## DECLINE OF THE SPECIES

Sparse regeneration contributes to the decline of *Fitzroya* but its reasons are not apparent. Methods of timber harvest do not appear to be the cause (Smith-Ramirez 2007). Even now, the silvical requirements of this species are still poorly understood. The most interesting clue is that *Fitzroya* seedlings appear after major disturbances such as volcanic ash deposits, lava flows, and landslides (Donoso et al. 1993; Parker & Donoso; Premoli et al. 2000). Another clue is its faltering reproduction. *Fitzroya* is dioecious, having either female or male reproductive structures, or strobili. This species produces few strobili, whether female or male (Grosfield and Barthelemy 2001).

The principal reason for the species decline appears to be climate change (Heusser 1966; Veblen et al. 1999). Although the scarcity of *Fitzroya* has been accelerated by human activity, its decline began well before human arrival and corresponds to the increasingly drier climate along the coastal range of Chile.

Reconstructing this record of decline is aided by the longevity of *Fitzroya cupressoides*, whose lifespan is second only to that of bristlecone pine. The oldest specimens to date have been 3,622 years (Lara and Villalba 1993). Tree-ring analyses from these specimens delineate four climate periods for South America: (1) A.D. 900–1070, which was a cool, moist episode; (2) 1080–1250, which was warm and dry; (3) another cool, moist episode from 1270–1670, coinciding with the Little Ice Age events reported in the Northern Hemisphere; and then (4) an episode of warmer conditions between 1720 and 1790.

Other temporal sources add supporting evidence. Fossil pollen records from Chile's Lake District, carefully recorded by Heusser (1966), show *Fitzroya*'s pollen count (or rather *Fitzroya-Pilgerdendron*, since these species' pollen cannot be distinguished) rose and ebbed repeatedly from the Late Glacial onward through the postglacial period. Soon after the last glaciers melted, *Fitzroya* forests expanded and spread, giving rise to pure stands (Heusser 1966). The pollen count decline began well before the Spanish conquest in the late sixteenth century and, as mentioned before, corresponds to increasingly drier conditions in south-central Chile.

Subfossil remains lend further support to this working hypothesis. Fossilized *Fitzroya cupressoides* stumps, unearthed by the major earthquake in 1960 (Roig et al. 2001), were estimated to be roughly 50,000 years old (Roig et al. 2001). They are proof that *Fitzroya* persisted in its present-day range and that climate conditions were similar (Roig et al. 2001).

*Fitzroya*'s populations have a long history of expanding and contracting within its present-day range. Even so, its temporal records show the local persistence of this species even during glaciation. This phenomenon of local persistence contrasts with the massive migration typical of many Northern Hemisphere forest tree species. A widely accepted explanation is that glacial cycles in southern Chile were milder than those in the Northern Hemisphere (Heusser 1966; Markgraf et al. 1995; Rodbell et al. 2009). In this ocean-dominated part of the world, Pacific Ocean currents might have caused incomplete ice sheets to form, leaving pockets of open terrain for refugial forest stands. Andean glacial history is so localized that it shows little or no parallel to the harsh Pleistocene glacial cycles in the Northern Hemisphere (Heusser 1966; Markgraf et al. 1995; Premoli et al. 2000; Rodbell et al. 2009).

## CONCLUSIONS

*Fitzroya* has a remarkable history over the past 50,000 years, surviving glaciation, earthquakes, and other seismic activity within its present-day range. Its local persistence provides a sharp contrast to the massive migration typical of many Northern Hemisphere forest tree species during the same time period. Learning more about this peculiar species would bring a better understanding of environmental change on a global scale, a complement for the more complete record for Northern Hemisphere temperate forests. □

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*Claire G. Williams is the Distinguished Scholar at the Forest History Society.* *This article is excerpted from C. G. Williams, V. Martinez, and C. Magni, "Ice-age persistence of* Fitzroya cupressoides*, a Southern Hemisphere conifer," presented at the Third International Metasequoia Conference, Osaka, Japan, August 3–8, 2010; the paper was published in its proceedings and will appear in the* Japanese Journal of Historical Botany. *The research was funded by the National Evolutionary Synthesis Center (NESCent) and from a Fulbright Senior Specialist grant from the Fulbright Chile Commission organized by Professors Victor Martinez and Carlos Magni, University of Chile, Santiago.*

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